

# **MERCURY CONTROL WITH THE ADVANCED HYBRID PARTICULATE COLLECTOR STATEMENT OF WORK**

## **PROJECT DESCRIPTION**

### **Objective**

The overall project objective is to demonstrate 90% total mercury control with commercially available sorbents in the AHPC at a lower cost than current mercury control estimates.

### **Test Goals**

- \$ Determine if the bench-scale mercury breakthrough results can be duplicated when real flue gas is sampled.
- \$ Compare the level of mercury control with sorbents under similar conditions at the 200-acfm pilot scale between the AHPC and a pulse-jet baghouse.
- \$ Demonstrate 90% mercury capture for both a western subbituminous and an eastern bituminous coal.
- \$ Demonstrate mercury capture with the 9000-acfm AHPC at Big Stone.
- \$ Demonstrate 90% mercury capture over a longer time (3 months) with the 9000-acfm AHPC at Big Stone.

### **Scope of Work**

Three levels of testing are proposed:

1. Bench-scale tests with the existing EERC mercury sorbent testing system. This same system will also be used to sample real flue gas from the EERC 200-acfm pulverized coal-fired unit known as the particulate test combustor (PTC). A total of thirty 4-hr tests with the bench-scale unit are planned.
2. Pilot-scale tests with the PTC, which can be used with either a pulse-jet baghouse or the 200-acfm AHPC. This combustion system has been a workhorse for the EERC for many years and is the same system used for the earlier sorbent injection work as well as the Ontario Hydro method validation work. The PTC has consistently been shown to produce the expected mercury concentrations in the flue gas based on coal analysis and typically produces an  $\text{Hg}^{2+}/\text{Hg}^0$  split similar to that from full-scale power plants. Extensive mercury analysis will be conducted with both the Ontario Hydro method and mercury CEMs. A total of 6 weeks of testing with the PTC is planned.
3. Demonstration tests at the Big Stone Power Plant with a pilot-scale 9000-acfm AHPC. The Big Stone Power Plant has graciously agreed to continue hosting the AHPC beyond the

current testing to include mercury demonstration with the AHPC. A total of 5 months of additional testing are planned.

## **TECHNICAL APPROACH/WORK PLAN DEFINITION**

### **Statement of Work Including the Project Description and Test Logic**

To meet the objectives, the team proposes to use a five-task approach:

**\$ Task 1: Project Management, Reporting, and Technology Transfer**

**\$ Task 2: Bench-Scale Batch Testing** that ties the new work to previous results and links results with larger-scale pilot testing with real flue gas on a coal-fired combustion system.

**\$ Task 3: Pilot-Scale Testing** on a previously proven combustion system with both a pulse-jet baghouse and an AHPC to prove or disprove the research hypotheses.

**\$ Task 4: Field Demonstration Pilot Testing** at a utility power plant to prove scaleup and demonstration of longer-term mercury control.

**\$ Task 5: Facility Removal and Disposition**

#### **Task 1: Project Management, Reporting, and Technology Transfer**

Task 1 will include all of the project management requirements of the project, including planning, coordination among team members, supervision of tests, review of results, attending meetings, and all aspects of reporting.

In addition to the DOE quarterly reports and project final report, results of the work will be submitted for presentation at a minimum of three different conferences. It is anticipated that at least one of these will be DOE-sponsored, such as the previous contractor conferences sponsored entirely by DOE or conferences jointly sponsored by DOE with other organizations such as EPRI and EPA. Other likely conferences for presenting results of the research are the A&WMA (Air & Waste Management Association) annual meeting and a national or international conference on mercury.

One of the key requirements for transfer of research results to industry is one or more industrial partners. The project team includes W.L. Gore, which holds the exclusive license to the AHPC technology. This will ensure that the most recent data are available immediately to the company responsible for commercializing the AHPC. Demonstrating low-cost mercury control with the AHPC is of interest to Gore because it would likely increase the market potential of this technology even beyond the current level. Another key requirement for technology transfer is interest from an end user. The project team also includes the Big Stone Power Plant operated by Otter Tail Power Company. The presence of a utility power company on the project will ensure that results are immediately available to assist it in planning for regulation of mercury, should that be required.

#### **Task 2: Bench-Scale Batch Testing**

The bench-scale tests are for the purpose of verifying previous results, expanding on the SO<sub>2</sub> and NO<sub>2</sub> concentrations effect, and linking the synthetic gas results to the results with real flue gas. There are more individual bench-scale tests than pilot-scale tests, but the bench-scale tests are of short duration and represent only about 5% of the total project.

These tests will be completed with the existing EERC bench-scale mercury sorbent testing system that has previously been developed under other projects. This system has been extensively used to screen sorbents and develop an understanding of the effects of flue gas concentrations on mercury capture. Results using mercury CEMs at the outlet have proven to be highly repeatable and produce excellent mass balance closures when compared with independent mercury analysis of the spent sorbent. The 30 tests planned with the bench-scale unit are divided into three series that follow a logical progression. The first series of tests are bring done for two reasons: first, to ensure that results obtained by the EERC and others can be duplicated; second, to include SO<sub>2</sub> and NO<sub>2</sub> as variables. Series 1 tests, shown in Table 1, are intended to verify the previous bench-scale work and expand on the SO<sub>2</sub> and NO<sub>2</sub> concentration effect. In previous work, no tests were completed in which both the SO<sub>2</sub> and NO<sub>2</sub> were reduced at the same time. These results are expected to show whether the SO<sub>2</sub> and NO<sub>2</sub> concentration effects are additive and, once verified with real flue gas, serve as a basis to predict the sorbent capacity if the SO<sub>2</sub> and NO<sub>2</sub> concentrations are known. In all of these tests, an inlet Hg<sup>0</sup> concentration of 15 µg/m<sup>3</sup> will be used. Tests with an oxidized form of mercury are not planned because of the uncertainty

TABLE 1

Bench-Scale Series 1 B SO <sub>2</sub> and NO <sub>2</sub> Concentration									
Test No.	Sorbent Type	Temp., °F	Sorbent Concentration, mg	Flue Gas	SO <sub>2</sub> , ppm	HCl, ppm	NO, ppm	NO <sub>2</sub> , ppm	
1	LAC	275	150	Simulated	1600	50	400	20	
2	LAC	275	150	Simulated	500	50	400	20	
3	LAC	275	150	Simulated	200	50	400	20	
4	LAC	275	150	Simulated	1600	50	400	10	
5	LAC	275	150	Simulated	500	50	400	10	
6	LAC	275	150	Simulated	200	50	400	10	
7	LAC	275	150	Simulated	1600	50	400	5	
8	LAC	275	150	Simulated	500	50	400	5	
9	LAC	275	150	Simulated	200	50	400	5	
10	LAC	275	150	Simulated	Repeat Test to Be Selected				

over what actual form of mercury exists in real flue gas for various coals. In addition, previous EERC bench-scale tests showed that the LAC sorbent collects  $\text{HgCl}_2$  better than  $\text{Hg}^0$  over the temperature range from 225 to 325 °F. Between these two species,  $\text{Hg}^0$  represents the most difficult capture case. Further, the sampling tests with real flue gas are intended to identify whether there are significant differences between the synthetic flue gas tests with  $\text{Hg}^0$  alone and real flue gas where both  $\text{Hg}^0$  and  $\text{Hg}^{2+}$  are present. Each test will be for a duration of approximately 4 hr. The 150 mg of sorbent is equivalent to a sorbent-to-mercury ratio of 3700 after 3 hr of exposure. This concentration has been shown to provide consistent results in previous testing and is sufficient to accurately measure the amount of mercury in the spent sorbent for mass balance closure, which will be verified for approximately one-third of the tests.

The second series of bench-scale tests (Table 2) is for the purpose of comparing the bench-scale fixed-bed results sampling real flue gas to those obtained with simulated flue gas. These comparisons will be made for both a western subbituminous and an eastern bituminous coal. The simulated flue gas concentrations will be matched to actual concentrations measured in the combustion tests. Since these results are critical, both the real flue gas and simulated flue gas tests will be duplicated for QA. In addition, tests with lower sorbent concentrations will also be conducted with flue gases matched to the two coals to assist in selecting the best sorbent concentrations for the pilot-scale tests. The real flue gas tests will be completed as part of the first two pilot-scale tests in Task 3. These bench-scale tests will be conducted using a slipstream bench-scale system sampling flue gas during the proposed pilot-scale tests. These are critically important experiments that have never been done.

TABLE 2

Bench-Scale Series 2 B Real Flue Gas Comparison

Test No.	Sorbent Type	Temp., °F	Sorbent Concentration, mg	Flue Gas	$\text{SO}_2$ , ppm	HCl, ppm	NO, ppm	$\text{NO}_2$ , ppm
11	LAC	275	150	Real	Flue gas from western coal			
12	LAC	275	150	Real	Duplicate test western coal			
13	LAC	275	150	Simulated*	400	4	300	5
14	LAC	275	150	Simulated Duplicate*	400	4	300	5
15	LAC	275	50	Simulated*	400	4	300	5
16	LAC	275	150	Real	Flue gas from eastern coal			
17	LAC	275	150	Real	Duplicate test eastern coal			
18	LAC	275	150	Simulated*	1000	50	400	10
19	LAC	275	150	Simulated Duplicate*	1000	50	400	10
20	LAC	275	50	Simulated*	1000	50	400	10

\* Simulated flue gases will be determined from actual flue gas measurements during combustion tests; values shown are estimates.

After the series= two tests, the data will be evaluated to determine if the simulated gas tests provide comparable results to the tests with real flue gas, in terms of initial breakthrough capacity and desorption after 100% breakthrough. If the results are comparable, it will provide confidence in proceeding with the pilot-scale mercury capture tests. If the results are unexplainably different, then the project team, including DOE, will review the data and decide on whether to alter the test plan. Although not anticipated, if after review the consensus of the team is that meaningful results cannot be achieved even with a change in project direction, the decision may be made to end the project.

The third series of bench-scale tests (Table 3) is for the purpose of screening alternative sorbents. The IAC sorbent was chosen because of the excellent results seen in some of the previous EERC pilot-scale tests, especially at higher temperatures from 250EB350EF. The IAC also appears to be better at capturing Hg<sup>0</sup> than the LAC. However, since the IAC is more costly than LAC, it must be effective at lower concentrations than the LAC. The IAC will be evaluated with flue gas concentrations for both a subbituminous and a bituminous coal, at two concentration levels, and at two temperatures. Four additional screening tests will be conducted on other promising alternative sorbents to be selected based on new information and availability. The results from these tests will be used to prescreen alternative sorbents that have the potential to provide better mercury capture than the LAC. The most promising sorbent would then be further evaluated in pilot-scale testing in Task 3.

TABLE 3

Bench-Scale Series 3 B Sorbent Type								
Test No.	Sorbent Type	Temp., EF	Sorbent Concentration, mg	Flue Gas	SO <sub>2</sub> , ppm	HCl, ppm	NO, ppm	NO <sub>2</sub> , ppm
21	IAC	275	150	Simulated*	400	4	300	5
22	IAC	275	50	Simulated*	400	4	300	5
23	IAC	275	150	Simulated*	1000	50	400	10
24	IAC	275	50	Simulated*	1000	50	400	10
25	IAC	325	150	Simulated*	400	4	300	5
26	IAC	325	150	Simulated*	1000	50	400	10
27	New No. 1**	275	150	Simulated*	400	4	300	5
28	New No. 2**	275	150	Simulated*	400	4	300	5
29	New No. 3**	275	150	Simulated*	400	4	300	5
30	New No. 4**	275	150	Simulated*	400	4	300	5

\* Simulated flue gases will be determined from actual flue gas measurements during combustion tests; values shown are estimates.

\*\* New sorbents would be selected based on background data and availability.

### Task 3: Pilot-Scale Testing

Six weeks of testing are planned under Task 3. A week of testing includes an 8-hr heatup period on gas and then approximately 100 hr of steady-state operation firing coal. This allows for four 24-hr test periods where the PTC is operated around the clock. The planned 6 weeks of tests are shown in Table 4. The first 2 weeks will be for the purpose of generating baseline data without carbon injection for a bituminous and a subbituminous coal with both the pulse-jet baghouse and the AHPC. Each test will be for a duration of approximately 48 hr. These tests will establish the amount of mercury capture by fly ash and will determine whether the amount of mercury capture is different between the pulse-jet baghouse and the AHPC. It will also establish the inlet and outlet speciated mercury concentrations and whether there is a change in mercury speciation across both devices. A second purpose for these baseline tests is to provide flue gas to support the bench-scale testing with real flue gas under Task 2.

Weeks 3 and 4 are designed to prove the ability of the technology to control mercury at the 90% level with a PRB coal.

TABLE 4

Task 3 B Pilot-Scale Testing						
Week/ Test	Purpose	Coal	Collection Device	Sorbent Type	C:Hg Ratio	Injection Method
1-1	Baseline	WSB <sup>1</sup>	PJBH <sup>2</sup>	None	NA <sup>3</sup>	NA
1-2	Baseline	WSB	AHPC	None	NA	NA
2-1	Baseline	EB <sup>4</sup>	PJBH	None	NA	NA
2-2	Baseline	EB	AHPC	None	NA	NA
3-1	Hg capture, collection device	WSB	PJBH	LAC	3000 <sup>5</sup>	Type 1
3-2	Hg capture, collection device	WSB	AHPC	LAC	3000 <sup>5</sup>	Type 1
4-1	Hg capture	WSB	AHPC	LAC	3000 <sup>5</sup>	Type 1
4-2	Hg capture	WSB	AHPC	LAC	3000 <sup>5</sup>	Type 2
5-1	Hg capture	EB	AHPC	LAC	3000 <sup>5</sup>	Type 1
5-2	Hg capture	EB	AHPC	LAC	3000 <sup>5</sup>	Type 2
6-1	Sorbent type and concentration	WSB	AHPC	New 1 <sup>6</sup>	3000 <sup>5</sup>	Type 1 <sup>6</sup>
6-2	Sorbent type and concentration	WSB	AHPC	New 1 <sup>6</sup>	1000 <sup>5</sup>	Type 1 <sup>6</sup>
6-3	Sorbent type and concentration	WSB	AHPC	New 2 <sup>6</sup>	3000 <sup>5</sup>	Type 1 <sup>6</sup>
6-4	Sorbent type and concentration	WSB	AHPC	New 2 <sup>6</sup>	1000 <sup>5</sup>	Type 1 <sup>6</sup>

1 Western subbituminous.

2 Pulse-jet baghouse.

3 Not applicable.

4 Eastern bituminous.

5 Estimated concentrations, actual concentration will be based on previous testing.

6 To be selected.

Following the Week 4 tests, the data will again be reviewed to determine if objectives have been met and whether to proceed with the remaining tests as planned. If, after review, the consensus of the team is that meaningful results cannot be achieved even with a change in project direction, the decision may be made to end the project.

Week 5 is for the purpose of testing mercury control in the AHPC with an eastern bituminous coal.

Week 6 is for the purpose of testing alternative sorbents in the AHPC. The need for alternate sorbent testing will be somewhat dependent on the results with the LAC sorbent. If 90% mercury capture was already demonstrated with both coals at a low sorbent concentration (for example, less than 3000:1), then there may be no need to further evaluate other sorbents. In this case, Week 6 would be cancelled, and testing with the field AHPC would proceed. However, if results with the LAC sorbent have not met expectations and other sorbents look more promising or if other unanswered questions remain that could be tested in the pilot tests, Week 6 would be completed.

For all of the pilot-scale tests, extensive mercury sampling with both the Ontario Hydro method and mercury CEMs will be completed. The Ontario Hydro measurements will also provide a measure of the particulate collection efficiency of the AHPC. During each week, a total of two to three inlet and six to eight outlet Ontario Hydro samples will be completed. In addition, continuous outlet measurements will be completed with at least one mercury CEM (Semtech, Tekran, or PS Analytical). The exact instruments will be selected at a later time based on the most current information from other continuing mercury work at the EERC. Several shorter tests will also be completed at the inlet with the mercury CEMs. All other flue gases such as O<sub>2</sub>, CO, CO<sub>2</sub>, SO<sub>2</sub>, NO, and NO<sub>2</sub> will be monitored by CEMs on the PTC. Chloride concentration in the flue gas will be determined by Method 26A. The feed coals and fly ash samples (which will include the spent sorbent) will also be analyzed for mercury for each test. Approximately three ash samples will be submitted for leaching analysis for each coal type. These samples will also be made available for an air desorption test method that is being developed under EPA funding at the EERC. The specific subbituminous and bituminous coals to be tested will be selected at a later date. A logical choice for the subbituminous coal would be the coal burned at the Big Stone Power Plant; however, since several different subbituminous Powder River Basin coals have been used at this plant during the last year, the exact coal that would be used during the field testing is uncertain. A logical selection for the bituminous coal would be Blacksville since significant mercury test data for this coal already exist (both at the EERC and elsewhere); however, new information may point to a different coal as a better selection.

#### **Task 4: Field Demonstration Pilot Testing**

Big Stone Power Plant was commissioned for service in 1975. The unit is jointly owned by three partners: NorthWestern, MontanaBDakota Utilities, and Otter Tail Power Company. The unit is a 450-MW-rated, Babcock and Wilcox cyclone-fired boiler. The primary fuel for the first 20 years of operation was North Dakota lignite, but 4 years ago, the primary fuel was switched to Powder River Basin subbituminous coal. This fuel has approximately one-half of the moisture and one-third more heat

than North Dakota lignite. Almost all of the effects of this new fuel have been positive. However, one challenge that has occurred is the decreased efficiency of the ESP because of an increase in resistivity of the fly ash. The combinations of a very fine particle size produced from the cyclone-fired boiler and high ash resistivity make this a challenging test for the AHPC.

Demonstration of mercury control with the AHPC at the 9000-acfm scale at a utility power plant is the next logical step toward proving the commercial validity of this approach. Since the field AHPC will still be on location at the Big Stone Power Plant and we will have just completed the current Phase III demonstration testing, the system will be ready for mercury testing. The only modification required is the addition of a sorbent injection system. A total of 5 months of field tests are planned. The first month will be for baseline testing without sorbent injection to establish the mercury concentration, speciation, and amount of fly ash capture. A comparison will also be made of the mercury emissions at the plant stack with the AHPC outlet to determine if the amount of fly ash capture of mercury and possible change in mercury speciation across the plant ESP and AHPC are different.

The second month of field tests will be for the purpose of establishing the sorbent addition rate to achieve 90% mercury control. Following the second month of field testing will be a third project decision point. The field data will be reviewed to determine if an acceptable level of mercury control has been achieved, and the results will be compared with the 200-acfm pilot-scale tests. If results are acceptable, field testing will continue. If expectations have not been met and no alternatives such as testing another sorbent or altering the process are obvious, the decision may be made to end the project. Depending on the level of success with the LAC sorbent in the field and the pilot-scale test results with alternative sorbents, the third month will be for the purpose of evaluating alternative sorbents. If alternative sorbent testing is not necessary, then 3 months of longer-term testing with the LAC sorbent will be completed. The longer-term operation will establish whether there are any longer-term problems associated with the sorbent injection such as bag-cleaning problems. If alternative sorbents are tested during Month 3, then the longer-term demonstration testing would last only 2 months.

For the field testing at Big Stone, 4 weeks of intensive mercury sampling are planned. For the baseline testing, a total of 12 Ontario Hydro samples will include the inlet and outlet of the AHPC, the plant inlet to the ESP, and the plant stack. NO and NO<sub>2</sub> will be measured with a portable CEM; SO<sub>2</sub> and NO<sub>x</sub> will be obtained from the plant CEMs; and HCl will be determined with Method 26A. A mercury CEM will also be installed at the AHPC outlet for continuous measurements during the day. Coal and fly ash samples from both the plant ESP and AHPC will be analyzed for mercury. The second week of mercury testing will occur during the first month of carbon injection tests. Approximately, three inlet and eight outlet samples will be completed as well as mercury CEM measurements during the day. An additional 2 weeks of mercury sampling are planned during the third and fifth months of longer-term demonstration. In each of these weeks, two inlet and four outlet Ontario Hydro samples will be taken as well as outlet mercury CEM sampling during the day. Plant coal and AHPC ash samples will also be analyzed for mercury during the longer-term testing.

## **Task 5: Facility Removal and Disposition**

Since the bench-scale and pilot-scale systems already exist at the EERC, and are likely to be used for continuing research on other projects, it is expected that they will remain in place at the EERC after the completion of this proposed work and no facility removal will be required. The field AHPC will be dismantled and removed at the end of this project if no further testing is anticipated in support of subsequent work at the Big Stone Power Plant. If further testing were to be completed with the field AHPC at another site (funded by possible subsequent projects), the AHPC components would be moved to that site. If no other AHPC testing is anticipated, the salvageable AHPC components will be returned to the EERC, and the larger steel components will be disposed of as scrap steel. The site will then be restored to its original condition. The Big Stone Power Plant will be responsible for removing the 24-in. ductwork that breeches the plant ductwork, the electrical power lines, air supply lines, and communication lines once the project is complete.

## **Availability and Performance of Sorbent**

The LAC sorbent to be used in all three tasks is currently commercially available from Norit Americas as its Darco FGDJ sorbent. This sorbent has been widely used both for research on coal combustion systems and for incinerator applications. For the pilot-scale tests, the amount of required carbon is insignificant, approximately 2 lb/day. For the field demonstration tests, the maximum amount of carbon needed will be approximately 25 lb/day, assuming an inlet mercury concentration of  $10 \text{ } \mu\text{g}/\text{m}^3$  and a carbon:mercury ratio of 5000:1. Each month of testing would require approximately 750 lb of sorbent or a total of 3000 lb maximum for the planned 4 months of sorbent injection. The planned level of testing with the IAC sorbent would not go beyond the 200-acfm pilot-scale tests for which a maximum of 1 lb of sorbent would be required. If the IAC sorbent were to be tested with the 9000-acfm field AHPC, the required total sorbent amount would be 300 lb, assuming 1 month of testing at a mercury concentration of  $10 \text{ } \mu\text{g}/\text{m}^3$  and a carbon:sorbent ratio of 2000:1.

## **Installation, Operation, and Maintenance Plans**

All of the planned work will be completed with existing equipment that has already been installed and for which long-term operation has already been proven. The only planned modification necessary for completing the work is the installation of a dry powder injection system for the 9000-acfm field installation. The bench-scale system and the pilot-scale PTC have been used for many years at the EERC for other research. Both short-term and long-term maintenance plans already exist for these facilities. Operation and maintenance plans for the field AHPC have already been developed but will be more firmly established by the end of the current AHPC Phase III testing. At that time, the field AHPC will have been operated for approximately 12 months. The amount of carbon to be injected is small enough to expect no impact of carbon injection on the AHPC performance. Therefore, significant changes to the operation and maintenance of this facility are not expected.

## Project Milestone Schedule

TABLE 5

Milestone Schedule*									
	2001			2002			2003		
Bench Series	1	2	3						
Pilot Test/Weeks		1	2	3	4	5	6		
Field Testing			1	2			3	4	
Major Project Decision Points		1	2	3					
Project Management and Reporting	1	2	3	4	5	6	7	8	

\* Numbers shown correspond to Table 6.

## Work Breakdown Structure

TABLE 6

### Milestone Description and Work Breakdown Structure

Description	Completion Date*
<b>Bench-Scale Testing</b>	
1. Series 1	September 30, 2001
2. Series 2	December 31, 2001
3. Series 3	July 31, 2002
<b>Pilot Test/Weeks</b>	
1. Test/Week 1	November 30, 2001
2. Test/Week 2	December 31, 2001
3. Test/Week 3	February 28, 2002
4. Test/Week 4	March 31, 2002
5. Test/Week 5	August 31, 2002
6. Test/Week 6	September 30, 2002
<b>Field Testing</b>	
1. Baseline	February 28, 2002
2. Initial sorbent testing	June 30, 2002
3. Long-term demonstration	January 31, 2003
4. Removal of the field AHPC from Big Stone site	June 31, 2003
<b>Major Project Decision Points</b>	
1. Comparison of synthetic flue gas and real flue gas results	January 31, 2002
2. Effective mercury control established with pilot-scale AHPC	April 30, 2002
3. Effective mercury control established with 9000-acfm field AHPC	July 28, 2002
<b>Project Management and Reporting</b>	
Quarterly Report 1	September 30, 2001
Quarterly Report 2	December 31, 2001
Quarterly Report 3	March 31, 2002
Quarterly Report 4	June 30, 2002
Quarterly Report 5	September 30, 2002
Quarterly Report 6	December 31, 2002
Quarterly Report 7	March 31, 2003
Final Report	June 30, 2003

\* Assuming project start date of July 1, 2001.